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CHEMICAL PROPERTIES AND FERTILITY STATUS OF ANDISOLS IN COFFEE PLANTATIONS CONVERTED FROM FOREST IN JAMBI PROVINCE, INDONESIA

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ABSTRACT
The soil in the tropical forest volcanic plateau, especially that which has been converted into coffee plantations in Merangin Regency, Jambi Province, is classified as Andisols which generally contains high to very high levels of organic matter. However, their sloped terrain and high rainfall make them vulnerable to erosion, and poor farming practices can significantly reduce their fertility. The study aims to determine and examine the chemical properties and fertility status of soil in coffee plantations resulting from the conversion of tropical forests in Jangkat District, Merangin Regency, Jambi Province. The study used a survey method with a 1:75000 scale working map, obtained from overlaying the slope map with the land use map. Field observations showed that the coffee plantations in Muara Madras Village are located on flat to steep land with a slope of 3-60 percent. Soil fertility was evaluated using the soil fertility status criteria according to the Bogor Soil Research Centre 1995 with the criteria of five soil property variables, namely cation exchangeable capacity (CEC), base saturation (BS), C-organic, P_2O_5, and K_2O. Results showed that soils on slopes less than 15% were classified as low in fertility, while those on slopes greater than 15% were moderate. Both categories had an acidic pH, moderate CEC, and high P_2O_5. On slopes less than 15%, soil organic carbon (SOC) was high (4.34-4.36%) with very low BS (17.90-16.50%) and moderate K_2O (39.43-35.50 mg/100g). On steeper slopes, SOC was very high (5.12-5.48%), BS was low (29.37-18.60%), and K_2O was high (46.59-44.91 mg/100g). Maximum surface cover of soil with vegetation and litter can minimize the negative impacts of rainfall and topography on erosion, thereby controlling the decline in soil fertility.

KEY WORDS
Soil chemical properties, soil fertility status, andisols, coffee plantation.

The soils of Indonesia's tropical rainforests are mostly dominated by volcanic soils, Andisols. Conversion of tropical forests to agricultural land generally causes significant changes in soil properties in a short period of time. In many cases, this is often detrimental to the sustainability of soil functions (Anda and Dahlgren, 2020). Andisols are commonly found on volcanic slopes and develop through weathering of highland basalt rocks or cold volcanic mountain environments (Eswaran and Reich, 2005). They acquire unique properties that distinguish them from other soil types and are generally fertile. However, it covers only 1% of the earth's land area (Arnolds, 2013). Soil formed from volcanic material has unique morphological, chemical, physical, and mineralogical characteristics. It has a positive value for the chemical-physical and biological fertility of the soil, thus supporting optimal plant growth for sustainable agricultural production (Takahashi and Dahlgren, 2016). Initially, this soil is loose, friable, and often nutrient-rich and supports various production systems. However, because this soil is often found in sloping and exposed to high rainfall, it can experience erosion and damage to the cultivated layer, and fertility decreases drastically if not appropriately managed (Peret and Dorel, 1999).

The area of Andisols in Indonesia is 5,153,000 ha, and 2,594 ha of them on the island of Sumatra and 168,000 ha in Jambi Province (Hidayat and Mulyani, 2002). Most of the Andisols in Indonesia (61.99%) are in mountainous areas (slope gradient > 30%), the remaining 16.38% are in hilly areas (slope gradient 15-30 percent), and 12.93% on undulating land (slope gradient 8-15 percent) (Sukarman and Dariah, 2015). Therefore, one of the challenges Andisol soil faces in highland agriculture in Indonesia is erosion caused by rainfall and steep slopes. Erosion removes the topsoil typically rich in organic matter and nutrients, leading to a direct decline in soil fertility (Arsyad, 2010). Soil degradation and low soil fertility are the main obstacles to sustainable food production in tropical areas. Continuous decline in soil fertility will hamper agricultural production (Membrate et al., 2022).

Volcanic soil in Indonesia has a black or dark surface horizon or epipedon and a high organic C content, known as melanic or fulvic epipedon (Sukarman *et al*., 2020). Andisol soils in Indonesia are generally characterized by low bulk density, slightly acidic soil reactions, and cation exchange capacity of 22-30 cmol (+) kg^{-1}, low available P compared to total P, which is generally high due to very high P retention, (>95%). Generally, this land is productive for farming annual and perennial crops with relatively high productivity (Fiantis et al., 2005).

Andisols, the primary dryland agricultural soils in Indonesia with a humid and well-drained climate, are Udand. The results of soil sample analysis from various regions show that the texture of Andisol soil in Indonesia varies from clay to coarse clay, the soil reaction is slightly acidic, the organic matter of the topsoil is moderate to high, and the lower layers are generally low, the potential of P and K varies from moderate to high, the amount of exchangeable bases is moderate to high and dominated by Ca and Mg (some also K), the cation exchange capacity is mainly moderate to high with base saturation generally moderate. Thus, the natural fertility potential of Andisols soil is moderate to high (Hidayat and Mulyani, 2002). Soil fertility is the ability of the soil to provide physical, chemical, and biological characteristics that are beneficial to support plant growth. Altitude greatly influences its physicochemical properties (Membrate et al., 2022). Udands are most widely used for agriculture and generally support the highest population density. Large areas of Southeast Asia, Central Africa, Mount Cameroon in West Africa, and the Andean range in South America, as well as many of the volcanic islands of the Pacific, including Japan, are the main locations of Udands (Eswaran and Reich, 2005).

Andisols in Jambi Province, one of which is in Jangkat District, Merangin Regency, is classified as Hapludands with topography varying from flat to steep, but most have a slope of >15% (hilly and mountainous topography to very steep), and most of the land use is tropical rainforest and mixed farming with Arabica coffee as the primary commodity converted from tropical forests (Hartatik et al., 2005). Converting tropical rainforests into agricultural land alters their characteristics (Hati et al., 2021). Coffee is planted in rows along the slope to accelerate the erosion process and impact decreasing soil fertility (Henny *et al*., 2011). The growth of some coffee plants is not good, but farmers do not fertilize because they consider their land fertile; the soil surface is covered by litter from fallen coffee leaves and weeds between plants. However, on land with a slope of <15%, farmers do weeding because it is quite close and easy to reach from home, while on other land (slope >15%), no weeding is done. Some coffee plants grow well, and the soil surface is relatively clean with intercropping plants as shade for the coffee plants, but the number is small compared to the area of the coffee plantation. Good plant conditions are indicated by dense plant canopies, especially on land with a slope of 30-45 percent (Henny et al., 2024).

This study aims to determine and examine the chemical properties and soil fertility status of coffee plantations from the conversion of tropical forests in Jangkat District, Merangin Regency, Jambi Province. The results of the evaluation of soil fertility status can be used in planning the use and development of agriculture and soil fertility management.

MATERIALS AND METHODS OF RESEARCH

The research was conducted in Muara Madras Village, the capital of Jangkat District in the Merangin Regency. Geographically, the village is located at 101º50'0''-101º58'0'' East and 2º36'0''-2º44'0'' LS, 1035 m above sea level. The climate in Muara Madras Village is classified as Type B (Q value = 0.197, wet) with an average rainfall of 2,177.5 mm $year^{-1}$ (176.0 mm/month), wet months 9.1, dry months 1.8, temperature and humidity 17.3°C and 51.9% respectively. Land use in Muara Madras Village consists of forests, mixed farming, especially Arabica coffee plantations, dry fields, rice fields, and bushes, with topography varying from flat to steep (dominated by hilly to mountainous land (Henny et al., 2024).

The study used a survey method with a 1:75000 scale working map, obtained from overlaying the slope map with the land use map. Field observations showed that coffee plantations in Muara Madras Village are located on flat to steep land with a slope of 3-60 percent, with a plant age of 2-6 years. The number and determination of observation points and soil sampling used the purposive stratified random sampling method, and the number of points was proportional to the area of each SLH. Field observations show that coffee plants in Muara Madras Village are found on flat to mountainous land (Table 1).

Table 1 – Homogeneous land unit of survey area in Muara Madras Village, Jangkat District

HLU	Slope (%)	Topography	Wide (ha)	Number of observation points
1	3-8	Gently (wavy)	81.3	1
2	8-15	Slightly sloping (undulating)	83.6	3
3	15-30	Sloping (hilly)	113.2	3
4	30-45	Slightly steep (mountainous)	60.0	2
5	45-65	Steep	32.2	1
	Total		370.3	10

Table 2 – Criteria for assessing chemical properties of soil according to the Bogor Soil Research Centre Staff in 1983

Soil parameter	very low (vl)	low (l)	medium (m)	high (h)	very high (vh)
Organic-C (%)	< 1.00	1.00-2.00	2.01-3.00	3.01-5.00	> 5.00
P_2O_5 (HCl 25%) (mg/100g)	< 10	10-20	21-40	41-60	> 60
K_2O HCl 25% (mg/100g)	< 10	10-20	21-40	41-60	> 60
CEC (cmol(+) kg^{-1})	< 5	5-16	17-24	25-40	> 40
BS (%)	< 20	20-35	36-50	51-70	> 70

Table 3 – Assessment of soil fertility status using high (H), medium (M), and low (L) criteria of CEC, BS, P_2O_5, K_2O and organic-C soil

No	CEC	BS	P_2O_5, K_2O, organic-C	Fertilty status	No	CEC	BS	P_2O_5, K_2O, organic-C	Fertility status
1	H	H	> 2H without L	High	16	M	H	> 2M with L	Medium
2	H	H	> 2H without L	Medium	17	M	H	other combinations	Low
3	H	H	> 2M without L	High	18	M	M	> 2H without L	Medium
4	H	H	> 2M with L	Medium	19	M	M	> 2M with L	Medium
5	H	H	H M L	Medium	20	M	M	other combinations	Low
6	H	H	> 2L with H	Medium	21	M	L	3H	Medium
7	H	H	> 2L without H	Low	22	M	L	other combinations	Low
8	H	M	> 2H without L	High	23	L	H	> 2H with L	Medium
9	H	M	> 2H without L	Medium	24	L	H	> 2M with L	Low
10	H	M	> 2H with L	Medium	25	L	H	> 2M without L	Medium
11	H	M	other combinations	Low	26	L	H	other combinations	Low
12	H	L	> 2H without L	Low	27	L	M	> 2H without L	Medium
13	H	L	> 2H with L	Low	28	L	M	other combinations	Low
14	H	L	other combinations	Low	29	L	L	all combinations	Low
15	M	H	> 2H without L	Medium	30	VL	HLM	all combinations	Very low

The data collected were soil chemical properties, including pH, cation exchange capacity (CEC), exchangeable bases (Ca, Mg, K, Na) and base saturation (BS), soil P_2O_5 and K_2O, and soil organic carbon (SOC) and soil particle size distribution (SPZD). These data (except for SOC and SPSD) were primary data obtained through analysis of composite soil samples from topsoil (0-30 cm) in the laboratory. Soil reaction (pH) was determined using distilled water (pH H_2O) with a glass electrode pH meter, and soil CEC and exchangeable bases were determined through extraction of soil samples with 1N NH_4OAc pH 7.0; the ratio of the amount of these bases to the soil CEC is the soil BS. The P_2O_5 and K_2O values were determined by extracting soil samples with 25% HCl. Soil organic carbon and texture were secondary data (Henny *et al*., 2024). Furthermore, the results of the analysis of all soil variables were graded (high, medium, low) using the criteria of Soil Research Centre Staff in 1983 (Table 2) (Ritung et al., 2011). Soil fertility was evaluated using the soil fertility status criteria according to the Bogor Soil Research Centre 1995 with five variable criteria, namely cation exchangeable capacity (CEC), base saturation (BS), C-organic, P_2O_5, and K_2O (Table 3).

RESULTS AND DISCUSSION

The soil texture in the coffee plantation in Muara Madras Village is classified as moderate (loam and silty loam) to rather fine (silty clay loam), with the distribution of soil fraction dominated by silt (Table 4). This shows Andisols in Muara Madras Village, with the characteristics of Andisols in general. The composition of clay and sand fractions that are not too large is one of the characteristics of Andisols because these soils have unique physico-chemical properties and mineral composition, which are generally loose with a medium texture (dominance of silt) (Suratman *et al*., 2018). Soils developed from volcanic clastic materials involve diversity in soil classification and properties (Takahashi, 2020).

Table 4 – Soil fraction distribution and class texture in a coffee plantation in Muara Madras Village

Slope (%)	Soil particle size distribution (%)*			Class of texture*
	sand	silt	clay	
3-8	31.46	45.80	22,74	loam
8-15	26.76	53.27	19,98	silty loam
15-30	19.07	50.93	29,99	silty clay loam
30-45	16.24	60.42	23,35	silty loam
45-65	17.63	67.57	14,80	silty loam

**Henny et al (2024).*

Andisols, which are soils with volcanic ash as their parent material, are generally dominated by silt fractions that are easily eroded because they are smaller in size and cannot form bonds without the help of adhesive/binders), because they are not charged (Dariah *et al*., 2004). Soil texture is a physical properties of soil that is not affected by management and determines soil quality; it is unchanging, permanent, or inherent (Islam and Weill, 2000). However, if the land is sloping and the surface of the land is open, the soil texture can change because the soil and its parts are eroded, and erosion is selective. The finer soil fractions are carried first and more; as a result, the eroded soil has a higher percentage of sand (Troeh et al., 2004). The soil under the coffee stands in Muara Madras Village has a silt fraction that tends to be higher on land with a higher slope (Table 4). This is due to better plant growth, more weeds covering the soil surface, and thicker litter on land with a slope of more than 15% due to farmers not clearing the land from weeds (far from settlements). On the other hand, land with a slope of less than 15% is close to settlements, so farmers carry out soil maintenance in the form of weeding or weed removal but do not fertilize because they consider their land to be fertile enough (conversion from forest). More vegetation and litter cover means providing maximum protection against the threat of erosion (Henny et al., 2024). Erosion and its selectivity are higher on land that is relatively free from weeds and litter even though the topography is gentle and undulating (slope gradient <15%), indicated by less silt fraction and more sand fraction compared to land with a slope >15%.

Soil organic carbon (SOC) is high on land with a slope of less than 15% but very high on land with a slope of more than 15 % (Table 5), It shows that volcanic soils are characterized by their ability to retain SOC because of volcanic ash materials contain dark-colored, non-crystalline (short-range-order) high-organic carbon minerals. The SOC of

Andisols in Indonesia varies from 1.24 to 22.46 percent, and there is a decrease in the SOC of Andisols due to its use for plantation or horticultural crops (Sukarman and Dariah, 2020). Higher organic matter contents can be found in Andisols that occur in warm and humid climates, where degradation should be rapid. Andisols in Sumatra Island have lower total P and available P compared to those in Java Island because the volcanic material that is the parent material has a lower primary apatite mineral content (calcium phosphate) compared to Andisols in Java Island. Allophane is the most reactive clay mineral because it has a large specific surface area and many active functional groups. Due to its shape and size, allophane has very high porosity and can fix high amounts of phosphate (Sukarman and Dariah, 2015). Total potassium (K_2O) in the soil is classified as moderate (39.43-35.50 mg/100g) on land with a slope of <15% and high (46.59-44.91 mg/100g) on land with a slope of >15% (Table 4). This is related to the minerals containing K in the Andisol soil originating from the decomposition of primary minerals such as Muscovite, Biotite K-feldspar, and orthoclase and supported by high to very high soil organic C (Table 3).

Table 5 – Soil pH, CEC, BS, and exchangeable bases of coffee plantation in Muara Madras Village

Slope (%)	C-organic (%)*	pH	CEC (cmol (+) kg^{-1})	Exchangeable bases (me/100g)				BS (%)
				Ca	Mg	K	Na	
3-8	4.34*high*	4.99*a*	18.31*medium*	2.78*low*	0.35*very low*	0.27*low*	0.22*loe*	17.90*very low*
8-15	4.36*high*	4.86*a*	21.23*medium*	2.13*low*	0.46*low*	0.15*low*	0.17*low*	16.50*very low*
15-30	5.12*very high*	5.62*sa*	22.38*medium*	5.40*low*	0.52*low*	0.21*low*	0.22*low*	29.37*low*
30-45	5.31very high	5.87*sa*	24.42*medium*	5.98*low*	0.73*low*	0.17*low*	0.25*low*	32.70*low*
45-65	5.48*veryhigh*	5.85sa	24.21*medium*	5.00*low*	0.94*very low*	0.21*low*	0.21*low*	28.60*low*

**) Henny et al. (2024); a = aciditic, sa = slightly aciditic.*

The very high SOC on land with a slope of > 30% can be caused by the land being a forest that is cleared and used for coffee plants with thicker litter cover and more weeds, as previously explained (Henny et al., 2024). Forests are land uses with dense canopies and thick litter, so they effectively protect the soil surface and conserve soil organic matter (SOM). Conversely, SOC is lower on land with a slope of <15% with a plant age of 6 years, meaning that the land converted from forest has been used for longer. The open soil surface causes the SOM decomposition process to be faster and erosion to be greater so that the SOC content decreases. Higher organic matter contents can be found in Andisols that occur in warm and humid climates, where degradation should be rapid (Harsh, 2005). Conversion of Andisols from forest to agricultural land (intensive horticulture) which is given organic fertilizer has high resistance to long-term degradation, because this soil is able to absorb additional C so that it will have a positive impact on carbon mitigation (Anda and Dahlgren, 2020).

Soil reaction (pH) is acidic, and CEC is moderate in all lands with different slope gradients (Table 5). The characteristics of Andisols soil depend on its parent material (volcanic ash from volcanic eruptions); volcanic soil in Indonesia has a fairly wide pH range (3.4-6.7) with an average of 5.4, but pH values with a range of 4.5-5.5 are most commonly found. This shows that non-crystalline or amorphous clay minerals dominate volcanic soil in Indonesia because it has high rainfall and parent material that is andesitic or andesitic-basaltic. Allophane is a group of non-crystalline clay minerals that are most commonly found in volcanic soil in Indonesia, with a content of 1-34 percent (average 11) (Sukarman and Dariah 2015). This is also supported by the research results of Busyra and Firdaus (2010) which showed that the soil along the Bukit Barisan route in the Kerinci and Merangin Regencies (Mount Masurai) is dominated by Hapludand which develops from the parent material of Andesite and basalt tuff with a very acidic to slightly acidic reaction (pH 4.1-5.7).

Acidic soil reaction followed by moderate soil cation exchange capacity on all slope gradients (Table 5) can be caused by soil made from andesitic volcanic ash, which is generally acidic. Soil with low pH has a low capacity to bind cations. The CEC of Andisol soil in Indonesia is positively correlated with the content of soil organic C; the higher the content of organic C, the higher the CEC of the soil. The CEC value of Andisol soil in Indonesia varies from very low to very high (6.5-52.0 me/100 g), with an average value of 23.8 me/100 g, classified as moderate (Sukarman and Dariah, 2015).

Base saturation (BS) is classified as very low on land with a slope of <15% and low on land with a slope of >15%, dominated by Ca and Mg cations (Table 3). This can be caused by low soil pH (very acidic to acidic), as previously stated, due to the parent material being andesite volcanic ash (very acidic to acidic) (Sukarman and Dariah, 2015). The Annual Report of the Agricultural Research and Development Agency, Ministry of Agriculture in 2004 also showed that Hapludand soil in Jangkat District on the middle and lower slopes of Mount Masurai had a relatively low BS (Hartatik et al., 2005). The BS value depends on the soil pH; soil with low pH generally has a low KB (Hardjowigeno, 2010). The parent material of the soil influences the dominance of Ca and Mg in Andisol soil; in this case, the parent material of Andisol soil in the form of Andesitic material is dominated by primary minerals, which are a group of ferromagnesium minerals (easily weathered minerals) which contain a lot of Fe, Ca, Mg. This shows that Andisol soil in Muara Madras Village still has high mineral reserves as a Fe, Ca, and Mg element provider (Sukarman and Dariah, 2015). Low soil K and Na cations can be caused by their being more soluble than Ca and Mg cations, so they are easily washed out. The K and Na elements in solution form compounds that are always soluble, and percolation water will carry them to deeper layers until they are finally lost in the soil. In addition, it can also be caused by competition in the absorption of Ca, Mg, K, and Na elements by plants. If one element is higher, the other elements will be less absorbed (Munawar, 2011).

Low to very low base saturation and exchangeable bases in coffee plantations in Muara Madras Village are due to the low of soil pH. Anda and Dahlgren (2020) reported that the conversion of Andisols from forest to agricultural land (intensive horticulture) given organic fertilizer has high resistance to long-term degradation, because this soil is able to absorb additional C so that it will have a positive impact on carbon mitigation. The use of organic fertilizer also has an impact on reducing P fixation, increasing pH, available P, concentration of exchangeable base cations (Ca^{2+}, Mg^{2+} and K^{+}) and micronutrients (Zn, Mn and Cu).

The available P content is classified as very low (3.52-4.70 ppm) and the total P (P_2O_5) is classified as very high (46.76-68.22 mg/100g) (Table 6) because most of the P in Andisol soil is bound by amorphous clay minerals, especially Allophane, and is one of the chemical characteristics of volcanic ash soil which is dominated by non-crystalline or amorphous clay minerals (allophane, imogolite, ferrihydrite). Allophane can retain P up to 97.8% so that available P can be low to very low (Sukarman and Dariah, 2015; Fiantis et al., 2005; Hidayat and Mulyani, 2002). Andisols in Sumatra Island have lower total P and available P compared to those in Java Island because the volcanic material that is the parent material has a lower primary apatite mineral content (calcium phosphate) compared to Andisols in Java Island. Allophane is the most reactive clay mineral because it has a large specific surface area and many active functional groups. Due to its shape and size, allophane has very high porosity and can fix high amounts of phosphate (Sukarman and Dariah, 2015).

Table 6 – Available P, P_2O_5, and K_2O of soil of coffee plantation in Muara Madras Village

Slope (%)	P-tersedia (ppm)	P_2O_5 (mg/100g)	K_2O (mg/100g)
3-8	3.52 *very low*	46.76 *very high*	39.43 *medium*
8-15	3.52 *very low*	58.88 *very high*	35.50 *medium*
15-30	4.22 *very low*	60.28 *very high*	46.59 *high*
30-45	4.77 *very low*	68.22 *very high*	45.45 *high*
45-65	4.52 *very low*	64.70 *very high*	44.91 *high*

Total potassium (K_2O) in the soil is classified as moderate (39.43-35.50 mg/100g) on land with a slope of <15% and high (46.59-44.91 mg/100g) on land with a slope of >15% (Table 4). This is related to the minerals containing K in the Andisol soil originating from the decomposition of primary minerals such as Muscovite, Biotite K-feldspar, and orthoclase and supported by high to very high soil organic carbon (Table 3).

Several soil chemical properties variables have relationships between them, especially: a) CEC with OC pH and clay (R^2, 0.84 and 0.81); b) CEC with pH, and P-Bray with P2O5 (R^2, 0.73 and 0.72); and c) P-Bray with pH, P-Bray with P_2O_5, and pH, BS with OC, pH and CEC (R^2, 0.96-0.98) (Table 7). This shows that CEC depends on or is determined by OC content and pH value. The higher the OC content and pH value, the higher the soil CEC. Meanwhile, the R^2 value approaching one (0.96-0.98) indicates that P-Bray or available P is highly determined by pH and the collective influence between P_2O_5 or total P with pH; while BS is highly determined by the collective influence between OC with pH and CEC (Table 7).

Table 7 – The relationship between CEC, P and BS with other soil chemical properties of coffee plantation in Muara Madras Village

Variable	Regression model	R^2	Significant value
CEC - OC, pH, clay	CEC = 7.82 + 9.43 OC - 5.85 pH - 0.01 clay	0.84	1.80 > 0.49
CEC - OC, pH	CEC = 7.97 + 9.83 OC - 6.29 pH	0.84	5.38 > 0.16
CEC - OC	CEC = 1.35 + 4.22 OC	0.81	12.55 > 0.04
CEC - pH	CEC = -2.15 + 4.46 pH	0.73	8.31 > 0.06
CEC - clay	CEC = 24.09 - 0.09 clay	0.04	0.12 < 0.75
P_2O_5 - pH	P_2O_5 = -11.52 +13.11 pH	0.60	4.45 > 0.13
P-Bray - pH	P-Bray = -2.24 +1.17 pH	0.96	73.51 > 0.00
P-Bray - P_2O_5	P-Bray = 0.55 + 0.06 P_2O_5	0.72	7.73 > 0.07
P-Bray - P_2O_5, pH	P-Bray = -2.06 + 0.02 P_2O_5 + 0.96 pH	0.98	52.91 > 0.02
BS - OC, pH, CEC	BS = -71.36 -16,74 OC + 30.1 pH + 0.68 CEC	0.97	10.95 > 0.22
BS - pH, OC	BS = -65.96 + 25.85 pH - 10.08 OC	0.96	25.34 > 0.04

The soil fertility status on land with slopes of <15% was classified as low (combination of criteria number 21 in table 3) with acidic soil pH, moderate CEC, and high P_2O_5 on all slopes, but OC was classified as high (4.34-4.36 percent), base saturation (BS) was very low (17.90-16.50 percent), moderate K_2O (39.43-35.50 mg/100 g). However, land with a slope > 15%, the fertility status is classified as moderate with OC was classified as very high (5.12-5.48 percent), low base saturation (29.37-18.60 percent) and high K_2O (46.59-44.91 g/100 g), combination of criteria number 22 in table 3 (Table 8).

Table 8 – Soil fertility status of coffee plantation in Muara Madras Village

Slope (%)	Criteria of					Soil fertility status
	CEC	BS	P_2O_5	K_2O	Organic-C	
3-8	medium	very low	very high	medium	high	LOW
8-15	medium	very low	very high	medium	high	LOW
15-30	medium	low	very high	high	very high	MEDIUM
30-45	medium	low	very high	high	very high	MEDIUM
45-65	medium	very low	very high	high	very high	MEDIUM

Very low BS, even though OC is high, CEC and K_2O are moderate, causing the soil fertility status to be low because soil with low pH has a low capacity to bind cations, and such soil is considered infertile (Sukarman and Dariah, 2015). However, soil with low BS and high K_2O gives a moderate fertility status (Table 5). Soil fertility status is determined not only by soil K_2O but also by BS, which is highly dependent on pH, while CEC is positively correlated with soil organic C. This shows that high SOC does not always provide high soil fertility status because soil fertility is highly determined by CEC and KB, which are chemical properties closely related to soil fertility. Land with high CEC, when dominated by base cations Ca, Mg, K, and Na (high base saturation), can increase soil fertility, but when dominated by acid cations Al and H (low base saturation), can reduce soil fertility (Hardjowigeno, 2010).

The more fertile land with a slope of >15% shows that agricultural practices and their management impact the nature of Andisol soil. The efficiency of erosion control in the cropping system greatly determines the fertility and sustainability of the agricultural system on steep land. According to cropping practices, slope and high rainfall lead to a very high but variable erosion risk (Peret and Dorel, 1999). The results of this study also show that maximum land cover by vegetation and litter can eliminate the negative effects of rain and topography on erosion so that it can control damage and decrease soil fertility (Arsyad, 2010).

CONCLUSION

The soil fertility status on land with slopes of <15% and >15% were classified as low and moderate, respectively, with acidic soil pH, moderate CEC, high P_2O_5 on all slopes, but soil organic carbon (SOC) was classified as high (4.34-4.36 percent), base saturation (BS) was very low (17.90-16.50 percent), moderate K_2O (39.43-35.50 mg/100 g) on slopes of <15%; while on land with slopes of >15%, SOC was classified as very high (5.12-5.48 percent), low base saturation (29.37-18.60 percent) and high K_2O (46.59-44.91 g/100 g). Maximum surface cover of soil with vegetation and litter can minimize the negative impacts of rainfall and topography on erosion, thereby controlling the decline in soil fertility.

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